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SOVIET SPACE PROBES STUDY THE MOON

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ABSTRACT. The Luna-16, Luna-17, Zond-8, and Lunakshod-1 moon missions of September - November 1970 are described.

The three autumn months of 1970 - September, October, and November - /2*** were marked by three dazzling flights of the Soviet lunar probes.

Exactly 280 hours in space; — this is how long the "Luna-16" probe, launched in the USSR at 16:26 Moscow time on September 12, was on its journey. After 280 hours, at 8:26 on September 24 the probe landed in the Soviet Union carrying a sealed container with lunar surface specimens. The experts who made this grandiose flight possible reported to the Communist Party and the Soviet Government leaders that they successfully solved a radically new technological problem of sending an automatic probe to another celestial body, acquiring lunar surface specimens, and returning them to the Earth.

The flight of Luna-16 is just one step in the work of Soviet space researchers who actively study the Moon by means of probes. Flights of unmanned probes to the moon and other planets, being much cheaper than manned flights and eliminating the risk to human life, are today the

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*** Numbers in the margin indicate the pagination in the original foreign text.

most versatile and efficient method at the disposal of today's planetary scientists. The flight of Luna-16 clearly demonstrated that a sample of another celestial body can in fact be brought to the earth without the direct intervention of human hands. This triumph of the world's science and technology is proof of the great progress made by Soviet automation and control science, and their development does indeed get close attention in our country.

Five weeks after the flight of Luna 16, on October 20, the "Zond-8" lunar probe was launched to fly around the Moon. The objectives of this flight included a further improvement of all systems under actual space flight conditions on the Earth-Moon-Earth trajectory. In addition, a number of scientific experiments designed to increase our knowledge about the Moon and the space around it were performed during the flight. The return of the probe to Earth tested a new version of a ballistic re-entry into the atmosphere from the side of the northern hemisphere. During the final portion of its trajectory, the probe was guided by the flight control center located on the territory of the Soviet Union, which made it possible to much more accurately follow its flight during the re-entry stage. Zond 8 splashed down within a specified region in the Indian Ocean in the immediate vicinity of the predicted splashdown point.

Finally, on November 10, the Soviet "Luna-17" automatic probe was launched toward the Moon. As indicated by a TASS communique, the operations of leaving the orbit of an artificial moon satellite and a soft landing of Luna 17 on the Moon's surface were accomplished with the aid of a unified landing stage. Luna 17 carried a "Lunokhod-1" moon vehicle. Thus, for the first time in the history of lunar research, the unmanned probes made it possible to perform scientific experiments, not only at the landing location, but also at various distances from it depending on the choice of the scientifically most interesting objects. Lunokhod 1 serves as a prototype of the means of transportation that will be necessary later in the following stages of the Moon's exploration and conquest.

The flight of Luna 16, whose characteristic features were repeated again during the flight of Luna 17, included a number of important technical modifications.

In contrast with the previous Soviet lunar probes and the Surveyor spacecraft, for the first time in astronautics, the soft landing of Luna-16 on the lunar surface was made from the orbit of an artificial moon satellite. This type of solution required that the probe perform a number of additional precise maneuvers.

During the approach to the Moon, the probe was first injected into a practically circular selenocentric orbit 110 km over the lunar surface. Two maneuvers, performed during the following two days, transferred the probe to an elliptical orbit whose apolune was only 15 km. On the morning of November 20, retrorockets were fired and Luna 16 left its orbit. A precise commanded terminal sequence was performed, and the probe soft-landed with high accuracy in a specified region of the Sea of Fertility.

Up to that time, a similar Moon landing maneuver was used only by /3
the manned Apollo spacecraft, where the most critical operations involving the selection of landing site, orientation, and maneuvering were left to the crew members. The successful realization of a similar landing scheme by an unmanned probe directed by commands from the Earth is a new frontier in the design of spacecraft. The landing scheme in question assures very high landing accuracy in any given region, and in principle it permits delivery of a lunar probe to any point on the Moon. This fact will make it possible in the future to greatly expand the borderlines of the lunar territory that can be investigated.

The capabilities of lunar probes will also be expanded by another new feature which was tested during the flight — namely, the landing during the lunar night. Luna 16 successfully landed on the surface of the Moon and started performing its scheduled operations under the conditions of lunar night almost 60 hours after sunset. The temperature of the lunar surface had by that time fallen to several tens of degrees Celsius below zero. This indicates that the useful life of probes on the surface of the Moon will in the future be greatly extended. Neither the landing at night, which imposes special requirements on the functioning of the on-board equipment, nor complicated temperature conditions of its operation will present an obstacle to performing scientific experiments at any time necessary for this purpose.

Among the new factors accompanying the flight of Luna 16, it should also be noted that it landed in the western region, located far from the center of the visible side. The landing site lies 41' to the south of the lunar equator at a longitude of 56°18', approximately 250 km in the north-north-western direction from the center of the major Langren ring formation. The site lies at a considerable distance from the previous landing sites of probes and spacecraft.

The closest point investigated by other probes lies at a distance of some 900 km from the landing site of Luna 16. Because of this choice of landing site, Luna 16 took a sample of the lunar surface at a distance of almost 1000 km from the Apollo 11's landing site and more than 2000 km from the landing site of Apollo 12. Thus, the lunar rock specimens brought back to the Earth, together with the earlier obtained data, will enable us to greatly expand our knowledge about the origin and structure of the only natural Earth satellite.

The return from the Moon is one of the most complicated new features of the flight of Luna 16. The flight had a truly dazzling finish. The probe was injected into the Moon-Earth trajectory in passive flight without a single correction and made the entire return trip with practically no deviations from the calculated trajectory. It landed on the Earth with such a high accuracy that it was visually detected at an altitude of approximately 2000 m by the crew of the recovery helicopters. This clearly shows the degree of perfection and reliability of all automatic systems.

In a way similar to Luna 16, the Luna-17 probe made a soft landing in a region lying at a very large distance from the center of the visible lunar hemisphere. The landing site was in the western coastal region of the Sea of Rains, and its coordinates were 35°00' west longitude and 38°17' north latitude. However, the flight program of Luna 17 also had important distinguishing features: both the number of maneuvers and the time spent in orbit around the Moon were reduced. This means that both the accuracy of trajectory calculations and the accuracy of the command system became higher.

These flight features of the new Soviet lunar probes indicate that successful solutions were found to many scientific and engineering problems involved in the effective utilization of unmanned probes in space.

The range of scientific problems that can be solved with the help of spacecraft steadily becomes wider and wider. The selection of optimal methods of obtaining scientific information is of great importance in this connection. One of the important aspects of the solution of this entire problem involves an efficient combination of unmanned and manned spacecraft.

As far as the study of the Moon and the planets is concerned, the Soviet space program has given a great deal of attention (and continues to do so) to the development of unmanned spacecraft, which a great number of times have demonstrated their high reliability and efficiency. Already in the first stage of the Moon exploration with the help of unmanned probes, the Soviet space experts tested diverse trajectories which are in principle possible in the flight to the Moon. New versions of translunar flight, guided fall to a given point, and flight around the Moon were tested. Soft landing on the surface and a creation of an artificial Moon satellite were achieved later. The next complication of the program involved returning the probe to the Earth from both the orbit around the Moon and directly from its surface.

From the point of view of the volume of scientific information, the lion's share of the information about the Moon was also obtained with the help of lunar probes. The probes in the "Luna" and "Zond" series have already performed a very wide set of studies of the natural satellite of our planet. In particular, because of the information transmitted by them, it was established that the Moon has no significant magnetic field and lacks radiation belts. The probes took pictures of the far side of the Moon, which led to the completion of the first general map of this celestial body.

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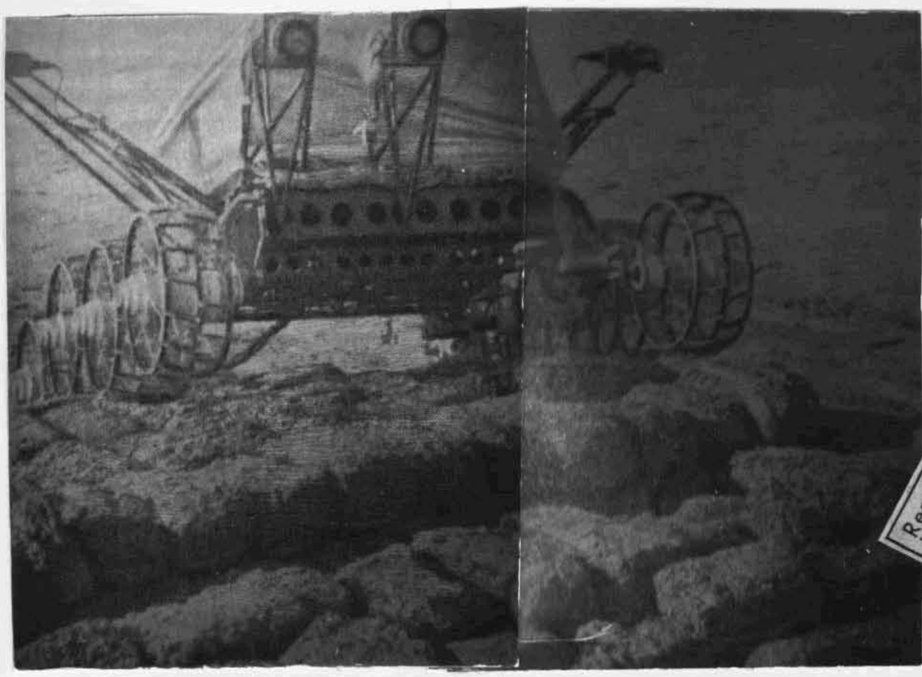
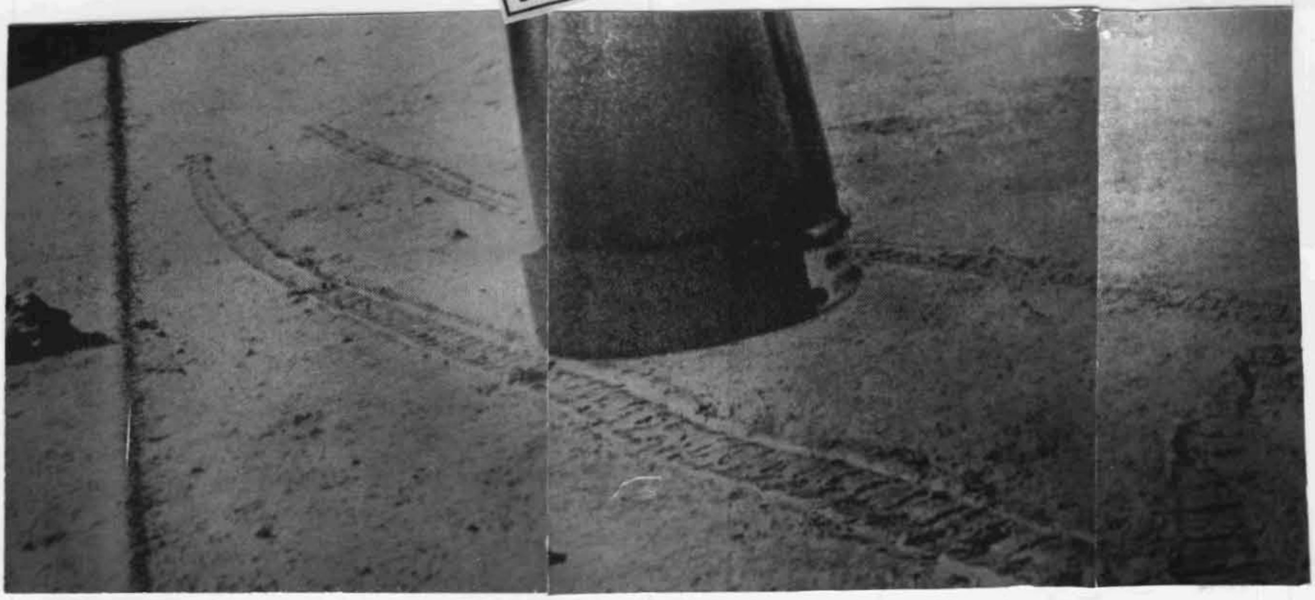


"Lunokhod-1" on the lunar surface

TASS Photographic Chronicle



Lunar panorama and first tracks made by the Soviet "Lunokhod-1" vehicle
TASS Photographic Chronicle

The first data on the microstructure of the lunar surface, on the density and mechanical properties of the lunar soil, and the first panoramas of the lunar landscape were obtained with the help of unmanned probes.

An extensive body of scientific data on the Moon and the space around it were obtained using artificial moon satellites. This is how the first data on the characteristic features of the gravitational field of the Moon were obtained. On the basis of the data obtained from the lunar probes, it was established that on the moon there are rocks whose composition is close to the basalt-type volcanic rocks which are very common in the Earth's core.

This short list of basic scientific results obtained with the help of probes should give an idea of the enormous possibilities involved in the exploration of space.

An equally important factor is the fact that space research done with the help of unmanned devices is relatively inexpensive. Experts have calculated that the total cost of the Apollo program is approximately 25 billion dollars. Manned flights to other bodies in the solar system will probably be undertaken only if they are justified and necessary. "We shall also in the future use unmanned spacecraft as they are efficient and reliable instruments of scientific exploration", President of the Academy of Sciences of the USSR, Academician M. V. Keldysh emphasized, during a press conference on the flight of Luna 16.[1]

Luna 16 brought back to the earth a column of lunar soil weighing over 100 g, obtained by digging to a depth of 35 cm. The sample was composed of fine dust with pieces of rocks and minerals, in which the fraction of large grains increased with the depth. The external form /5
of the lunar soil resembles dark concrete. Its color changes markedly depending on the lighting. The soil easily sticks together forming individual pieces. There are grains of melted rocks which glitter and sparkle against the dark background color of the powder. Among the crystalline grains under a microscope, one can see minerals of greenish and brownish color with traces of fracture. The pieces of rocks can be mostly classified as basalts.

Certain structural features of the lunar soil can also be observed. There are definite differences in their physical properties as compared with terrestrial rocks. For example, the density strongly depends on the character of packing, and ranges from 1 to 2 g/cm^3. The interesting fact is that, for such a relatively high density, the lunar soil has very small heat conductivity.

A preliminary chemical analysis of the lunar specimens showed that, in contrast with the data obtained by Apollo 12, there is a tendency toward a lower content of elements in the fine fraction as compared with a dense

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(1) See "Priroda", 1970, No. 12, p.5.

rock. The thorium content and the uranium content are on the same order of magnitude. It is interesting to note that the content of cosmogenic inert gases (helium, neon, argon, xenon, and crypton) in the fine fractions is just as high as in the Luna-16 and Apollo-11 specimens. What one notices is that, in total content, the Luna-16 speciments are closer to the Apollo-12 samples obtained from the Ocean of Storms at a distance of about 2500 km from the landing site of Luna-16, than to specimens obtained by the Apollo-11 astronauts whose landing site was at a distance of 1000 km.

A series of preliminary analyses was followed by a comprehensive study of the lunar samples, which included an investigation of the chemical, physico-mechanical, mineralological, optical, electromagnetic, and other properties of the lunar soil.

An important place in the scientific program of Zond-8, just as in the programs of the preceding probes in the same series, was occupied by activities aimed at obtaining pictures of the Moon from various distances and under various conditions. The experiment ended by delivering photographic film to the Earth. The pictures of the Moon thus obtained are especially valuable, since they are free of disturbances caused by television transmission. In addition, on the Earth, it is possible to select optimal conditions for processing the films.

Lunar photography in all stages of lunar exploration has been one of the most important tasks. There is hardly any need for arguing that photographs of the lunar surface in various scales will provide the basic raw data that can be used by lunar cartographers. Moreover, photographs taken from outer space are of great importance if we want to improve our knowledge of the shape of the Moon as a whole. However, neither the first nor the second of these obviously important tasks exhaust the entire range of lunar exploration in which the new photographs of the lunar surface can be applicable.

The photographs obtained from various altitudes, at varying angles, and diverse conditions of solar illumination permit one to draw general conclusions about the structural features of various regions of the lunar surface. Today, as a result of studying the Moon with the help of spacecraft, one can appreciate the enormous contribution to our knowledge about the surface layer of the Moon which was made before, during the pre-spaceflight era on the basis of astrophysical, and primarily photometric data. Pioneering work in the area of lunar photometry was made by the outstanding Soviet astronomers such as V. G. Fesenkov, N. P. Barabashov, A. V. Markov, V. V. Sharonov. Unfortunately, the possibilities of terrestrial observations are strictly limited to only the visible lunar hemisphere and by the stationary location of the observer relative to the lunar surface. The use of spacecraft removes these restrictions. The numerous, repeated photographs of the Moon are in this relation a source from which rich scientific data can be obtained.

Repeated photographs of the lunar surface can also be of great importance in solving other current problems of selenology, for example, the extremely difficult problem of detecting present-day lunar activity.

The new data from the photographs of the lunar surface are also extremely important for continuing the study of the geological and morphological features of the lunar maria and highlands. This includes not only photographs taken from the space around the Moon, but also those taken directly from the lunar surface. In this connection, the lunar panoramas transmitted by Luna-9 and Luna-13, as well as by the probes in the Surveyor series, were very valuable. The lunar landscape visible in these panoramas has remained practically the same. The photographs obtained under various illumination conditions demonstrated various examples of the same relief. In addition, the small altitude of the probes brought the horizon substantially closer.

From this point of view, the opportunities presented by Lunokhod-1 for taking pictures from the lunar surface are enormous. First, we obtain a whole series of overlapping panoramas whose joint analysis will give us an idea about a considerable territory on the lunar surface. The scientific value of such materials is that for the first time it will be possible to compare the neighboring forms of the micro- and meso-relief located within the same region. It should be noted that comparisons of this kind, which have been obtained thus far, were as a rule based on material covering regions lying hundreds of kilometers apart.

The selection of a region in the Sea of Rains as the first lunar testing ground is by no means accidental. The Sea has for a long time fascinated selenologists. It is the largest annular sea on the visible /6
hemisphere. Its diameter ranges from 1100 to 1200 km. Its rim includes such well-known ranges as Jura, Alps, Caucasus, Apenines, and the Carpathians. Finally, the spears of the ray systems of the Copernicus and the Aristarchus extend toward the Sea from the south and southwest. Major craters from 50 to 100 km in diameter are located only in the coastal zone. Among them, the most noteworthy is Archimedes with its mirror-like bottom; Erastothenes with an opening at the top of central peak, which has fascinated geologists for a long time; Plato, which is distinguished by an unusually flat bottom, and finally Pytheas which is diamond-shaped. The highlands lying primarily in the northeast portion of the Sea also have their peculiar features. For example, the Pico mountain is covered with a network of cracks; the Piton mountain has a double opening at the top. In addition to the morphological features of the relief, the surface of the Sea is noteworthy for having features that can be associated with lunar activity. For example, in the region of Plato in 1948 a yellow-orange eruption was discovered, and "clouds" were detected in the neighborhood of the Piton. It is clear that the outer layer of the Sea covers the traces of the principal stages of formation. However, there does not exist even a single hypothesis that would explain the origin of the Sea of Rains.